Session 2

Detonation Propulsion – A Navy Perspective

Gabriel Roy

Office of Naval Research Global

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Propulsion and Detonation Engines
A Navy Perspective

Dr. Gabriel D. Roy
Associate Director
ONRG Singapore

IWDP 2013, Tainan
Taiwan
July 26-28, 2013

Contents

- **Introduction**
- Combustion Process
- Fuels
- Thermodynamic Cycle
- Conclusion

The Navy Challenge

- Every nation wants its Navy to be the best in the world
- It should be affordable
- It should be prepared
- It should be able to attract the right people
- It should provide the best possible environment
- It should be able to provide later career path
- Unlike the other services Navy has Water (surface), Underwater, Land and Air operations
- Operate in extremely hostile and difficult environment. This applies to personnel and assets.


Propulsion/Materials (platforms and weapons)

- Carrier decks: deck surface, blast plate, hull (maintenance-free)
- Submarines: hull (maintenance-free)
- Aircrafts (fixed wing): airframe materials, hypersonic regime
- Aircrafts (rotary wing): blades, brown-out
- Weapons: airframe, drag
- UAVs: Diagnostics, control







Propulsion system components

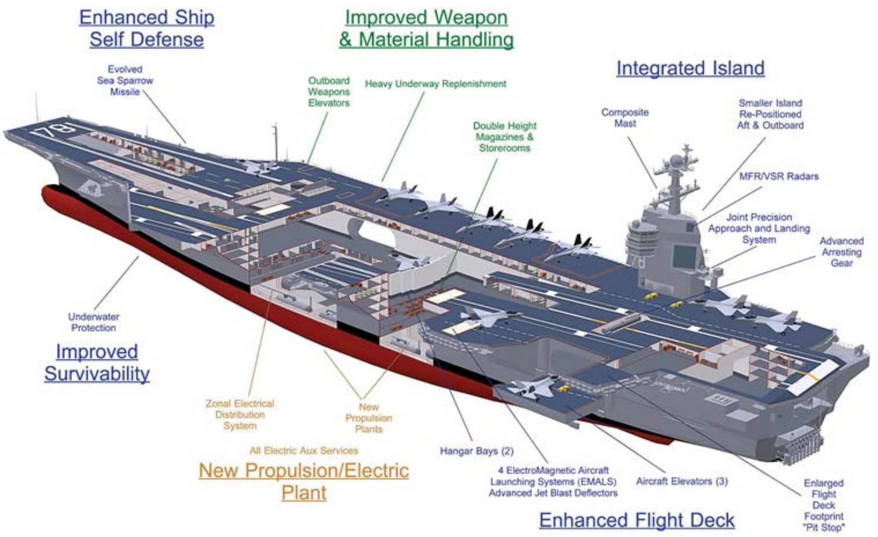

Challenges – How to address

- Challenges
  - Longer range
  - Increased speed
  - Reduced fuel consumption
  - Reduced cost of manufacture
  - Improve performance
  - Easier scaling
  - Reduced environmental impact
  - Reduced (zero) maintenance cost

- How to solve and make things happen:
  1. Improve combustion and propulsion efficiency by means of active control and other methodologies
  2. Increase the energy density of the fuel, so that for same fuel tank volume, increase in range, speed etc. can be achieved.
  3. Utilization of a more efficient thermodynamic cycle => Detonation Engines
  4. (New materials, coatings, nanotechnology)

Next Generation Aircraft Carriers

- Substantial improvements throughout

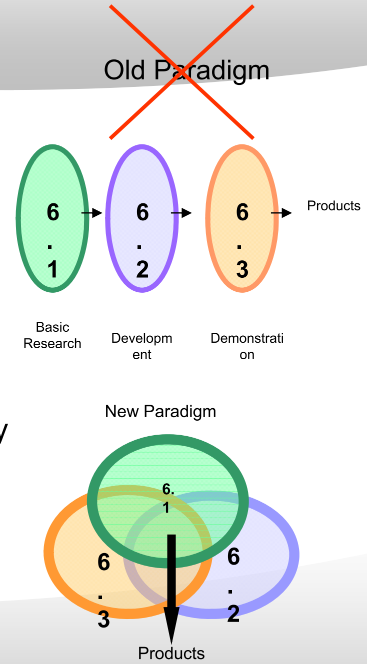


Program Strategy-A New Paradigm in Product Development

Programs are initiated after consulting with Government, Academia and Industry via Work shops and Review Meetings (Utilize past research, identify issues, define approach, establish teams, international collaboration)

- Government, Academia, Industry Advisory Panel with experts to provide critiques on major accomplishments and future direction.
- Academia, Industry, Government participation in all Review Meetings
- Encourage faculty and students to participate in Industry Programs (eg. GE/Cal Tech, GE/UC, P&W/MIT)
- Reliance (with AFOSR and ARO) and collaboration
- Wide participation in National and International Technical Conferences.

Contribute, Collaborate, Communicate (C cubed formula)



Originally presented
At the ONR 1987 Program
Review Meeting

Program Doctrine-A Combination of Science, Technology and Innovation

1. Science - scholarship driven, passion for discovering and inventing.
2. Technology - market driven, knowledge of customer demand.
3. Innovation - competition driven, advantage over similar product.

(1.2.3)

Progress both technical and economic

Caution: 1 not leading to 2 - technology valley of death.
2 not leading to 3 - loosing to competition.

Evolution of a program in the right direction at level 1 is critical for future transition and success of the investments.

Program Approach

Diffusion Flame, Detonation (Repeated)

Combustion Control, Distributed Counter Current, Plasma-Induced combustion

Stable Operation, Reliable, Increased Life, Range, and Speed Component Simulation

Reduced Noise, Emissions, Signatures

Platforms and Weapons New Engines, Improve Existing Engine

New Fuels New Cycles

Reaction Pathways Reduced Chemistry Molecular Modeling, Next Generation Diagnostics

Superior performance and environmental compliance at reduced cost.

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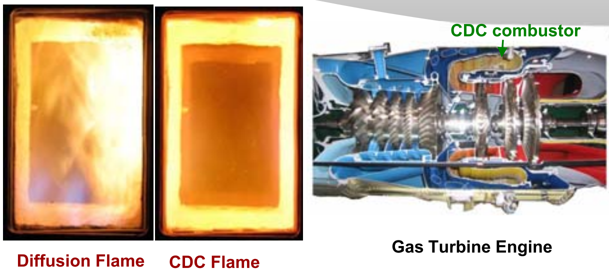
Development of Colorless Distributed Combustion (CDC) for Gas Turbine Engines



Diffusion Flame
NO=17ppm
CO=1310ppm

CDC Flame
NO=7ppm, 1 PPM [PM]
CO=12ppm, 35 PPM [PM]

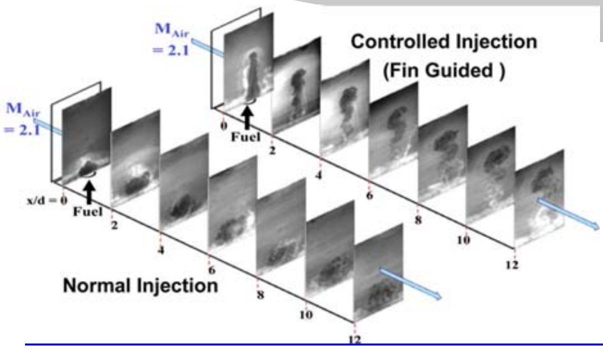
- Objectives
  - To examine feasibility of CDC at high thermal intensity (5→50MW/m^3-atm)
  - Examine the role of fuel/air mixing, gas recirculation and flowfield configurations on CDC
- Approach
  - Experimental: exhaust emissions, global imaging, acoustic signature, flow-field (PIV), thermal field
  - Numerical: flowfield (CFD), chemical kinetics, correlations

- Project/Program Components
  - Low Emission gas turbine combustor development with no visible flame color (colorless distributed combustion, CDC)
- Navy Relevance (Pay-off)
  - Application of low emission CDC combustor for stationary gas-turbine engines for power generation
  - Low noise emission
  - Increased combustor and turbine life

- **Major Accomplishment**
  - Demonstration of low emission CDC flames for range of thermal intensity (5-40MW/m^3-atm)

A. K. Gupta and K. H. Yu
University of Maryland

Scramjet Fuel Injection, Mixing, and Combustion Control



- Objectives
  - Explore "fin-guided" fuel injection concept
  - Understand key physical mechanisms
  - Assess/optimize its effectiveness quantitatively
- Approach
  - Optimize mixing enhancement and pressure losses in non-reacting gaseous fuel injection
  - Extend the results to liquid fuel injection and supersonic combustion experiments

- Project/Program Components
  - High Speed Weapons Technologies
  - Time-critical targets/ Long-range standoff
- Navy Relevance (Pay-off)
  - Enable volumetrically efficient scramjet operation by reducing combustor length
  - Reduce specific fuel consumption by increasing combustion efficiency
  - Increase specific thrust by reducing pressure losses due to fuel injection shocks

u Major Accomplishment
- Scale-up experiments of supersonic mixing control were conducted in 6"x3" Mach 2 tunnel
- Planar Mie-scattering images and wall-pressure measurements showed:
  - Two-fold increase in fuel penetration height
  - 45% reduction in jet-induced shock strength

POC: K.Yu
Univ. of Maryland

Passive Control of Combustion Noise of Turbine Engines

- Objectives
  - Develop high-temperature porous material for passive control of combustion noise
- Approach
  - Ultra-High temperature and strength foam material development by Ultramet
  - Combustion experiments performed U. Of Alabama
  - End-user input provided by Solar Turbines

- Project/Program Components
  - Optimize high temperature HfC/SiC Foam
  - Low-pressure combustion experiments to develop, validate, and refine the concept
  - High-pressure combustion experiments to implement the concept at turbine conditions
  - Integration of passive device with combustor
- Navy Relevance (Pay-off)
  - Reduction in combustion noise in navy installations such as aircraft engines
  - Potential to eliminate combustion instabilities

- Major Accomplishment
  - High-temperature HfC/SiC coatings have been developed, foam properties selected
  - Experiments have identified porous geometry parameters to minimize the combustion noise
  - Combustion instability is mitigated by our concept
  - High-pressure test facility has been developed

Name: Tim Stewart/Ajay Agrawal
Organization: Ultramet/University of Alabama

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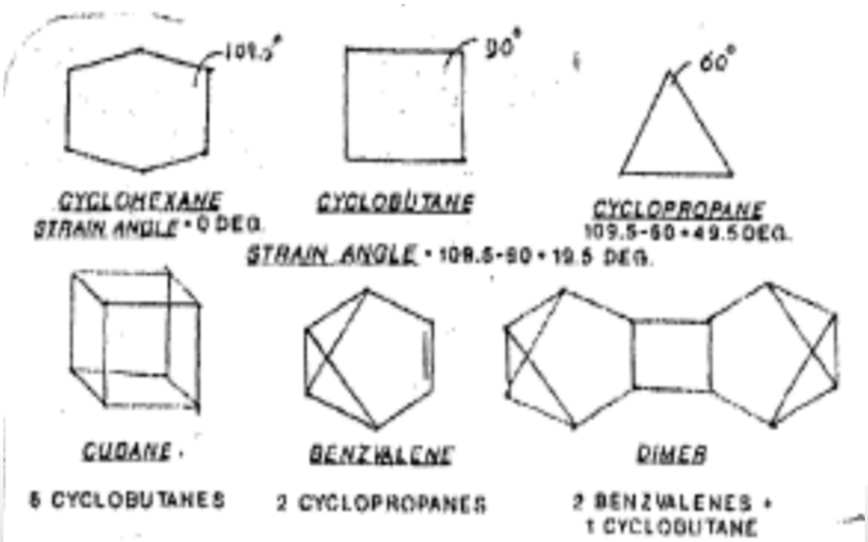
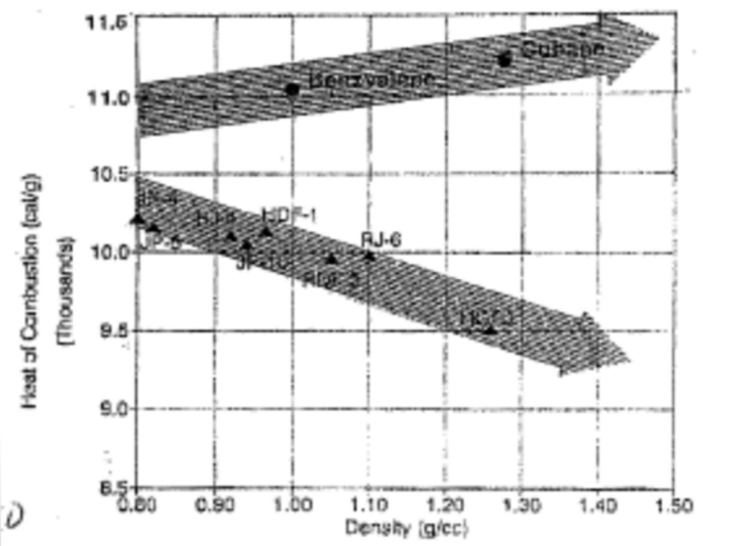
High Energy Fuels

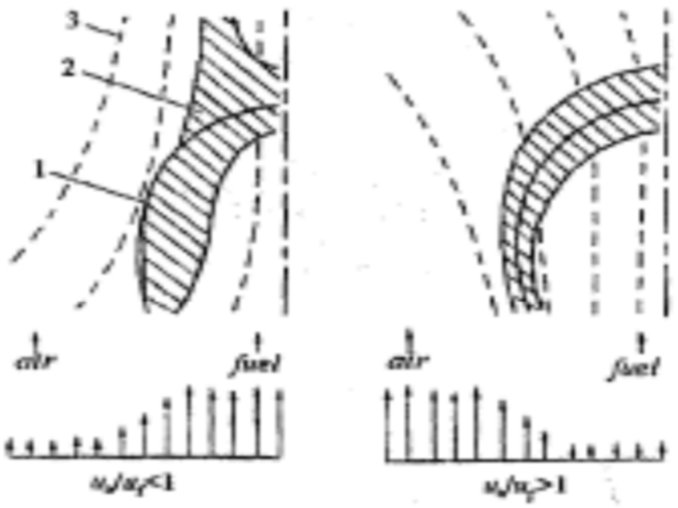


High Energy Fuels



Comparison of heat of combustion of various fuels

High Energy Fuels



Effect of reactant stream velocities on soot processes within laminar mixing layers for nonpremixed hydrocarbon-fueled flames. 1, flame sheet (typical); 2, soot layer (typical); 3, streamline (typical).

High Energy Fuels

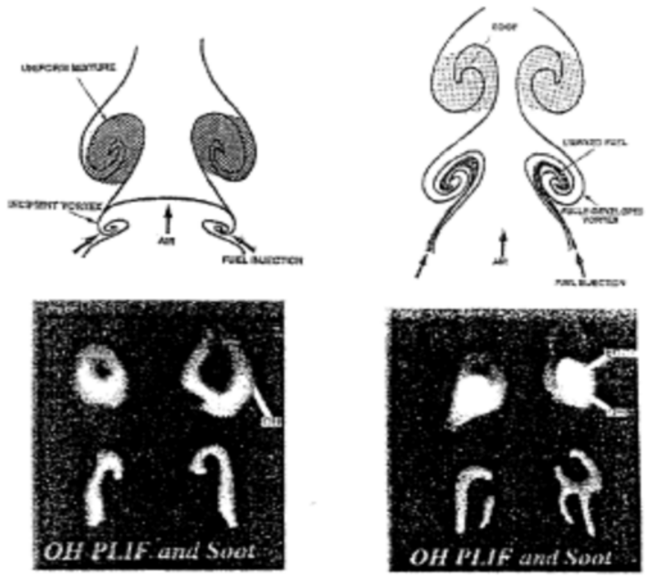
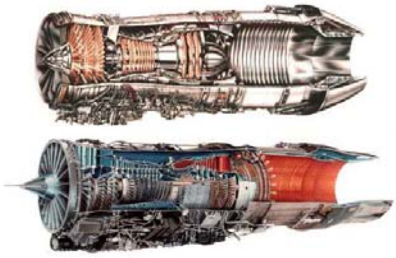


Fig. 8 Soot generation with and without controlled fuel injection.

Alternate biofuels Fuel Performance challenges

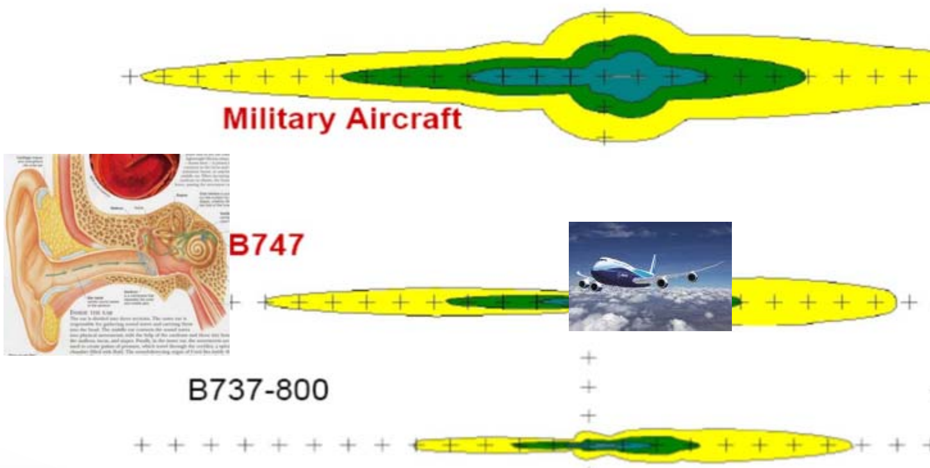


- Virgin Atlantic flew a Boeing 747-400 from London to Amsterdam with one of its four fuel tanks with 20% mix of biofuel from coconut oil and babasu oil – how much does this prove? What about real estate required for fuel
- Several engine and flight demonstrations have been made to show acceptable performance of biofuels.
- Shelf life and stability of these fuels
- Effects of long term operation on components (aromatics added to hydrocarbon fuels) possibility of coating formation?

Consistent energy density and specific thrust – make it questionable for military applications. (Innovative additives, genetic modifications, molecular manipulations – will help)

High temperature non-stick self-healing coatings that can prevent long term deposition of combustion products – a challenge

Noise issue from high speed jets
Mitigation of toxic particles in exhaust
Prevention of noise-induced health issues?



	B737	B747	Military
85 dBA	1.7	3.3	19.4 (sq. miles)
75 dBA	7.0	15.5	61.0 (sq. miles)
65 dBA	34	69.9	193 (sq. miles)

Courtesy: V Viswanathan, The Boeing Co

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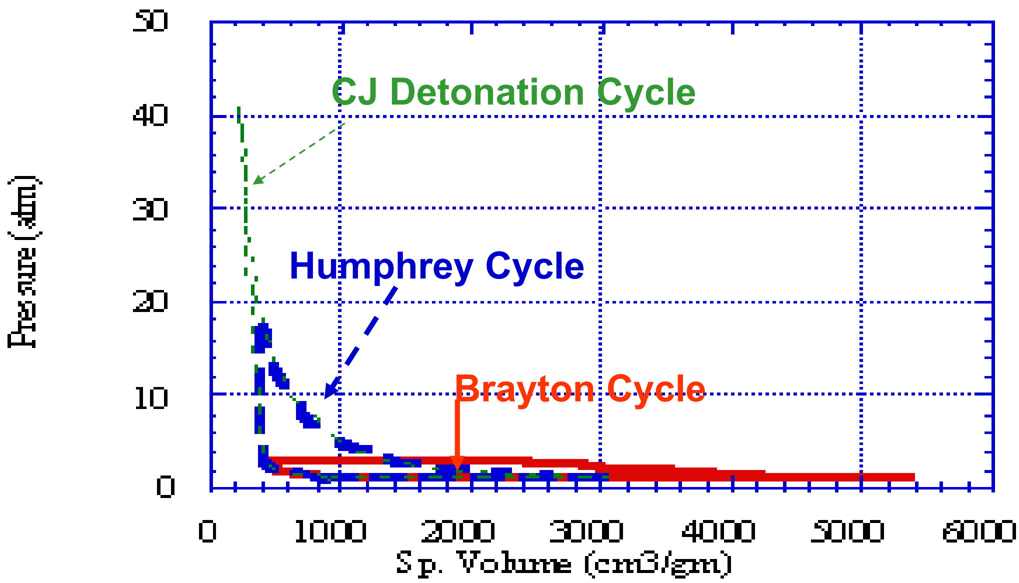
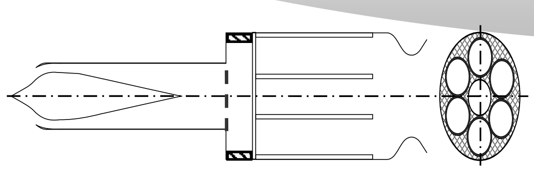
Pulse Detonation Engines

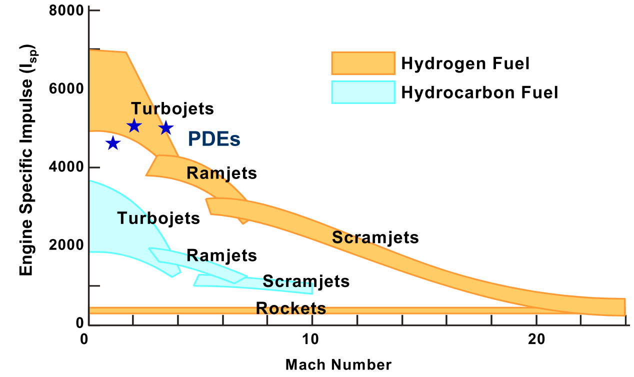
Comparison of Thermodynamic Efficiency of Various Cycles



Pulse Detonation Engines

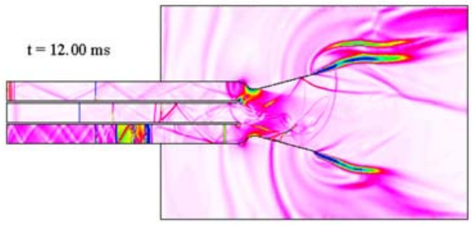


Characteristic performance by engine type



★ PDE Data: high-fidelity prediction based on full conservation laws with inclusion of all known effects

Typical density-gradient field in chamber



Advantages of PDEs

- High thermodynamic cycle efficiency
- High specific impulse (~20% > ramjet at M 2.1)
- Wide operation range & self aspiration
- Hardware simplicity
- Configuration scalability
- Low life-cycle cost

Pulse Detonation Engine

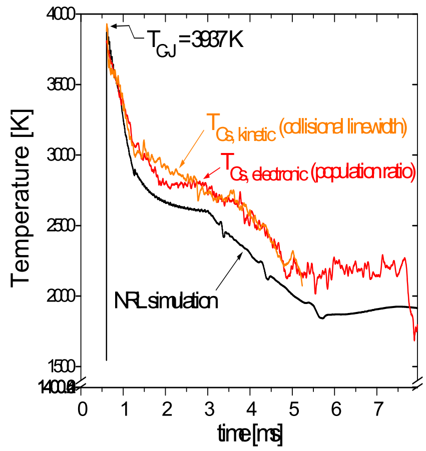
Advanced Computations and Diagnostics Paved the Way for Detailed Study of Processes Involved.

Conventional Approaches

1. DDT
   - Obstructions
   - Turbulence enhancers
   - Source: spark plugs
2. Direct Detonation Initiation
   - More powerful energy source
   - Reduction in system efficiency

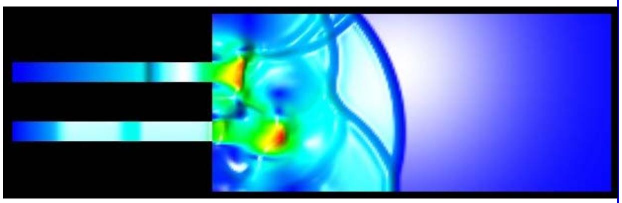
Innovative Approaches

1. Direct Detonation Initiation
   - Duel fuel (multi-fuel) operation
   - Fuel preprocessing
   - Plasma discharge ignition
   - Distributed energy deposition
   - Successive reactive shocks
   - Flame jet initiation
   - *Hybrid approach*



Measured and Computed Gas Temperatures for Detonation of Stoichiometric C_2H_4 / O_2

Pulse Detonation Engine Cycle Performance Prediction Code



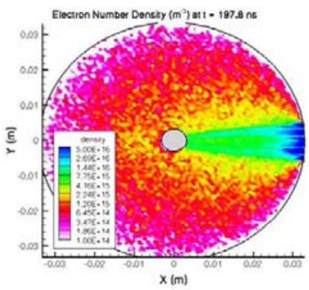
- Objectives
  - Simulation of multi-cycle operation of single and multi-tube PDEs
- Approach
  - Time resolved Q1D simulation of single tube PDEs with inlet and nozzle
  - Blending Q1D with multi-dimensional description for multi-tube PDEs with common nozzle

- Project/Program Components
  - Single tube multi-cycle PDE analysis capability
  - Inlet valve controls
  - Multi-tube multi-cycle PDE analysis capability

u Major Accomplishments
  - Multi-cycle simulation capability
  - Inlet valve controls
  - Impact of operating frequency on performance
  - Multi-tube, common nozzle PDE infrastructure

Metacomp Technologies

(STTR Collaboration-An Example) Transient Plasma Ignition for High Repetition Rate Pulse Detonation Engines



- Objectives
  - Development of next-generation ignition system for high rep-rate pulsed detonation engines
- Approach
  - Exploitation of transient plasma ignition via a combination of theory, computation, and experiment

- Project/Program Components
  - Support of Novel Pulsed Detonation Engines
- Navy Relevance (Pay-off)
  - Development of advanced, air-breathing propulsion technology that will be exploitable for rapid strike (from Mach 0 to Mach 4) scenarios

u Major Accomplishments
  - Experimental measurement of OH and ozone sensitivity to H_20, agreement with chemistry calculations
  - Identification of candidate mechanisms that influence detonation rep rate
  - Initiated multidimensional streamer modeling

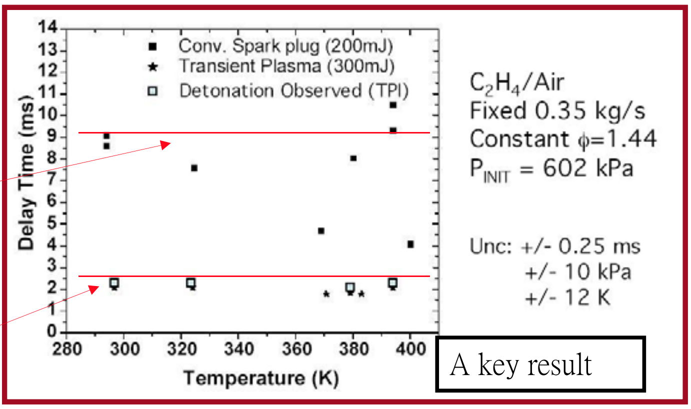
Jack Watrous
NumerEx

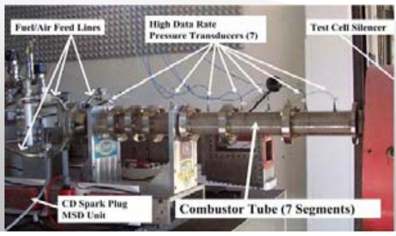
Pulse Detonation Engines

Transient Plasma Reactor with NPS PDE

Traditional Arc ignition
9 ms delay

USC
Transient plasma ignition
2 ms delay





With transient plasma we
- Considerably shortened the peaking time
- Created a detonation without added oxygen (propane-air)
- Improved the DDT time and increased the peak pressure
- ***Enabled higher repetition rate operation of the PDE***

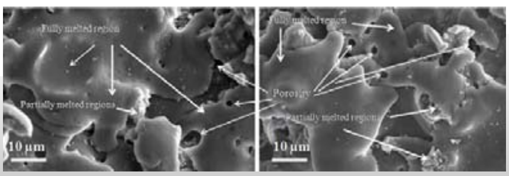
High flow rates (1/3 kg/sec)

Shortened DDT by factors >4 (9 to 2 msec)

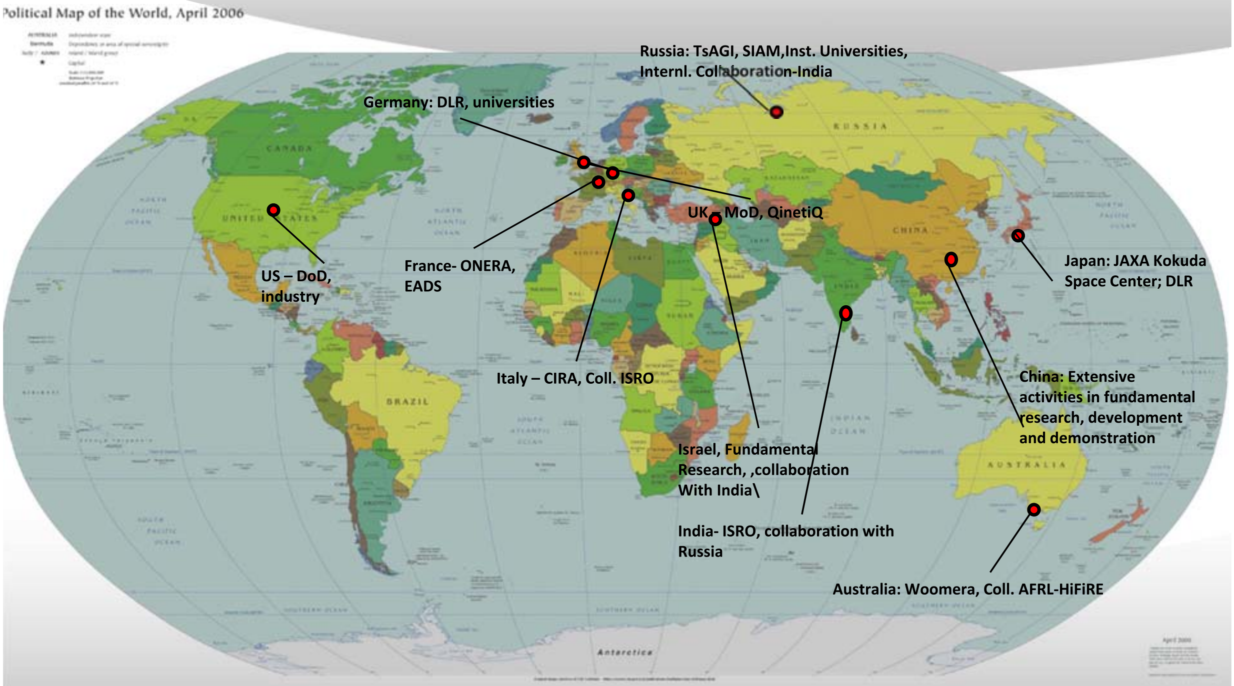
Recent Activities

Research
- Continuous detonations – U tube
- Collaboration of National University of Singapore with NPS.
- Continuous detonation at NRL
- Intermediate vanes for pressure gain- gas turbine combustor at Cambridge
- Nonlinear instabilities at IIT Madras
- Nano catalytic coatings at IIT Kanpur

Conferences/Workshops
- ICPCD, Monte Negro
- CDP Workshop, Bourges, France
- IWDP 2011, Korea
- IWDP 2012, Japan
- IWDP 2013, Taiwan
- International conference on Hypersonic Air Breathing Propulsion, Dec. 2013, India



World wide interest in Hypersonic (M=5+) Systems



Major Issues Addressed and To Be Addressed

- Addressed
  - Detonation Initiation
  - Detonation Repetition
  - Detonation Diagnostics
  - Control of Detonation Flows
  - Predictive Tools
  - System Analysis
  - Hybrid (PDE to gas turbines)
  - Pulsed detonation (mature)
  - Continuous Detonation (mid stages)
  - Rotating Detonation (mid stages)
  - Spinning Detonation (early stages)

- To be Addressed
  - Tailored Fuels
    - High Energy Density
    - Easily Detonable
    - Storage, Shelf Life
  - Noise
    - High Peak Noise Levels
    - Repetitive Noise
    - Acoustic Wave Interaction

Material Issues, Research Opportunities

- Wall Cooling
- Environmental Effects
- High Heat Release
- High Speed Flows and Wall Interaction
- Fatigue – Thermal and Mechanical
- Crack Propagation
- Weight Constraints
- Corrosion Resistance
- Magnetic Interference
- Abrasion Resistance
- Reduced Drag
- Functional Coatings
- Chemical Effects
- “Flexible” Coatings

Functional and Smart Materials
Nano-Structured Materials
High Temperature Materials, Advanced Ceramics
Nano-Catalysts, Catalytic Coatings
Polymers and Composites, Nano-Composites
Piezoelectric and thermoelectric materials
Nano-Fibers

Advanced coatings (Thermal barrier, physical and chemical vapor deposition, multi-layered and nano-crystalline, smart, and bio-coatings etc.)

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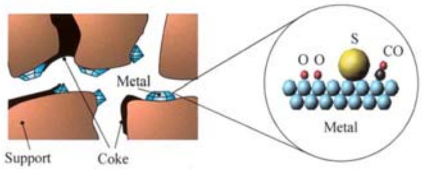
Concluding Remarks

- Future Navy has to meet conflicting requirements – increased range and speed with reduced noise and emissions, improved performance and wider operating envelope - all at reduced production, maintenance and operating costs.
- New thermodynamic cycles and combustion control methodologies, nano catalytic, plasma enhanced combustion etc. need to be developed.
- Functional materials, nano-composites, tailored coatings and surface treatment of materials are needed to meet the operating environment and conditions.



Innovation in combustion processes, tailored fuels and detonation-based propulsion are of paramount importance. Application-oriented Inter disciplinary research, collaboration of government, producer, manufacturer, and consumer, and international cooperation are vital to meet these challenges and seek practical solutions

Contribute, Collaborate and Communicate

Detonations…..

If detonation is our present quest's ultimate destination,
I may say, with some confidence, we have seen the horizon.
But if detonations are to drive a new generation of engines,
I have indeed miles and miles of waters to sail across.

But the deep waters seem to be calmer than I envisioned;
Yes, the tides are high and unpredictable, but I am not afraid.
The best sailors, trained in turbulent waters, are on board;
Yet, I look for more to help me further along the road.

Detonation is a new frontier to me, but I have the will to steer,
And if you have the willingness, strength and desire-
Together we can conquer, capture and control this frontier,
And look above to see detonation-driven engines flying in the air!

Thank You!